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Correlation Measurements of Charged Particles and Jets at Mid-Rapidity with Event Activity at Backward-Rapidity in $\sqrt{s_{\mathrm{NN}}} = 200\,\mathrm{GeV}$ p+Au Collisions at STAR

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Abstract

Semi-inclusive charged jet spectra per trigger at STAR are presented binned by event activity (EA) as determined by the Beam Beam Counter (BBC) signal in the Au-going direction. The selected EA determination is motivated by correlations between the number of charged tracks in the Time Projection Chamber (TPC) ($|\eta| < 1$) and EA ($\eta_{\mathrm{EA}} \in [-5, -2]$) which are also presented. The jet spectra per trigger at high EA are suppressed relative to the spectra at low EA. A PYTHIA investigation refutes that the suppression results from a trivial autocorrelation between jet kinematics and the acceptance of the EA and the TPC.

Keywords: small systems, p+Au, STAR, semi-inclusive, jets

1. Introduction

The discovery of the quark-gluon plasma (QGP) is a principle success of heavy ion physics, the investigation of which remains a primary focus in the field. In that search, small system (p/d+A) collisions were generally assumed to have insufficient energy densities to form a QGP, and therefore used for comparison to benchmark QGP effects in A+A collisions. One principle way to quantify hot nuclear effects is via nuclear modification factors (R_{AA}), which are yields in A+A collisions taken in a ratio to those in pp collisions scaled by appropriate geometric factors. Separately, p/d+A collisions benchmark cold nuclear effects in the nucleus [1].

However, starting with the observation of a long range near-side ridge in high multiplicity pp collisions by CMS in 2010 [2] most of the signals indicative of flow in A+A collisions have now been observed in small system collisions [3, 4]. This has motivated measuring jet spectra in small systems to check for other QGP-like signals.

Measurements of minimum bias (MB) $R^{\mathrm{jet}}_{p/d+\mathrm{Au}}$ at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) are, as expected, consistent with unity [5, 6, 7, 8]. However, when binned by modeled geometric overlap into central (peripheral) collisions, the ATLAS and PHENIX measurements report suppression (enhancement) for central (peripheral) collisions. The modification increases with jet energy and ATLAS notes that it appears to be a function of the Bjorken-x of the proton (x_p) [6].

ALICE has made two measurements of jet spectra binned by event class. The first modified the method to classify events to address statistical difficulties in determining the geometric factor, and found no modification of jet spectra with central/peripheral binning [9]. The second reports a limit on p_{T}-independent out-of-jet-cone charged-energy transport which is not consistent with the jet modification observed at ATLAS and PHENIX [10]. However, the measurements at ATLAS and PHENIX observed modification only at higher x_p values than those measured at ALICE. This is consistent with the jet modification trend as a function of x_p.

These previous measurements collectively motivate the STAR result presented in these proceedings; namely, the first semi-inclusive jet measurements in small system collisions at both (a) RHIC energies and (b) x_p at which ATLAS and PHENIX measurements report jet spectra modification.

2. Correlation of Central Tracks and Triggers to High Backward-η EA

The event activity (EA) is defined as the sum of ADC hits in the Au-going Beam Beam Counter (east BBC) located at $\eta \in [-5, -2]$. The EA deciles are defined from the EA distribution in MB events. To collect sufficient collisions with jets, a second dataset is analyzed from events triggered by energetic hits in the Barrel Electromagnetic Calorimeter (BEMC) which has $|\eta| < 1.0$ and full azimuthal coverage. The calorimetric energy deposited in the BEMC by a particle, scaled by the perpendicular component of the particle's trajectory, i.e. $\sin(\theta_{\mathrm{particle}} - \theta_{\mathrm{beam-line}})$, comprises the E_{T} of a BEMC hit. The triggers listed in Fig. 1 are the collection of the maximum E_{T} hit in the BEMC in each event.

The distribution of the average number of charged tracks per event ($\langle N_{\mathrm{ch}} \rangle$) per EA decile increases monotonically with EA, as demonstrated in the bottom panel of Fig. 1. Requiring increasing E_{T} in the triggers, and consequently requiring higher energy jets, results in an approximately constant addition in $\langle N_{\mathrm{ch}} \rangle$ to the MB distribution. This result, in addition to the rapidity gap between the EA signal and the charged tracks, affirms the EA definition for use in binning the semi-inclusive jet spectra.

Additionally the change in distribution of events with respect to EA with increasingly higher E_{T} requirements is notable (see Fig. 1, top panel). A positive correlation is naively expected and is observed. The decrease in this positive correlation as the trigger E_{T} requirement increases is reminiscent of a similar observation of mid-η charged jets and EA at high backward-η in p+Pb collisions by CMS [11], and may be a signal of theorized physical mechanisms such as energy conservation or proton size fluctuation [12].

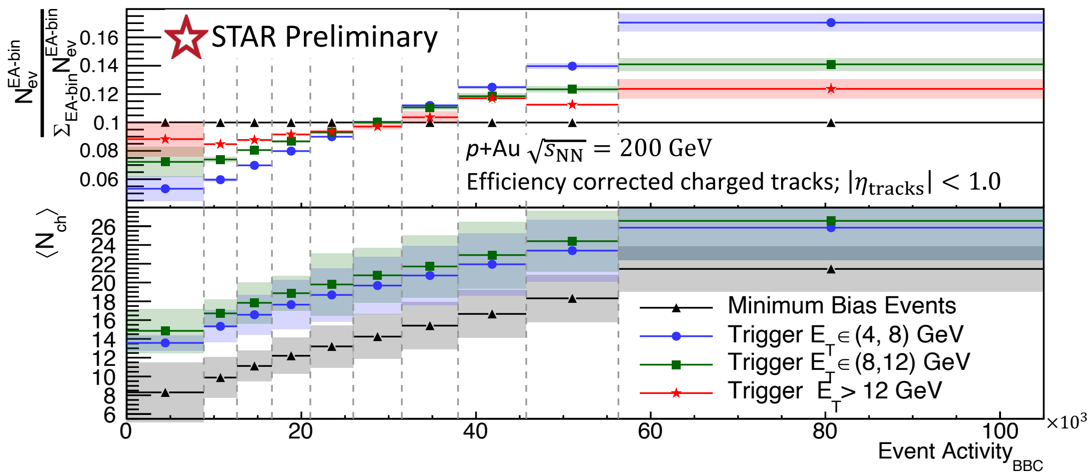

Figure 1. Top: Distribution of probability of events per trigger. The deciles are defined to contain 10% of the MB events per bin. Bottom: Average number of charged tracks per event per EA decile. The values for events with Trigger $E_{\mathrm{T}} > 12$ GeV are statistically limited and therefore excluded from the results.

3. EA binned semi-inclusive jet spectra

Events are selected with a BEMC trigger ($E_{\mathrm{T-max,BEMC}} > 8\,\mathrm{GeV}$) and grouped into high and low EA. The high (low) EA groups correspond to the highest 30% (70-90%) of the distribution and labeled as 0-30% (70-90%) EA. Within each event, charged tracks are clustered by the anti-k_{T} algorithm [13] with $R = 0.4$. In each event, jets are binned in their azimuthal angle relative to the azimuthal angle of the trigger ($\Delta\phi \equiv \phi_{\mathrm{jet}} - \phi_{\mathrm{trigger}}$). The resulting jet spectra per trigger, along with high-to-low EA spectra ratios, are shown in Fig. 2.

The jet spectra per trigger are preliminary and uncorrected for detector effects. However, the spectra ratios shown in the bottom panel are not anticipated to change within uncertainties because (a) it has been shown via detector simulations [14] that the charged track reconstruction efficiency is not EA dependent and (b) there is negligible background and, consequently, negligible combinatorial jets. The second point is demonstrated by spectra in Fig 2. At "jet-like" energies, $p^{\mathrm{ch}}_{\mathrm{T,jet-raw}} > 10\,\mathrm{GeV}/c$, the transverse ($\pi/8 < |\Delta\phi| < 5\pi/8$) jet spectra is two orders of magnitude smaller than those of trigger-side ($|\Delta\phi| < \pi/8$) and recoil-side ($7\pi/8 < |\Delta\phi|$) jets.

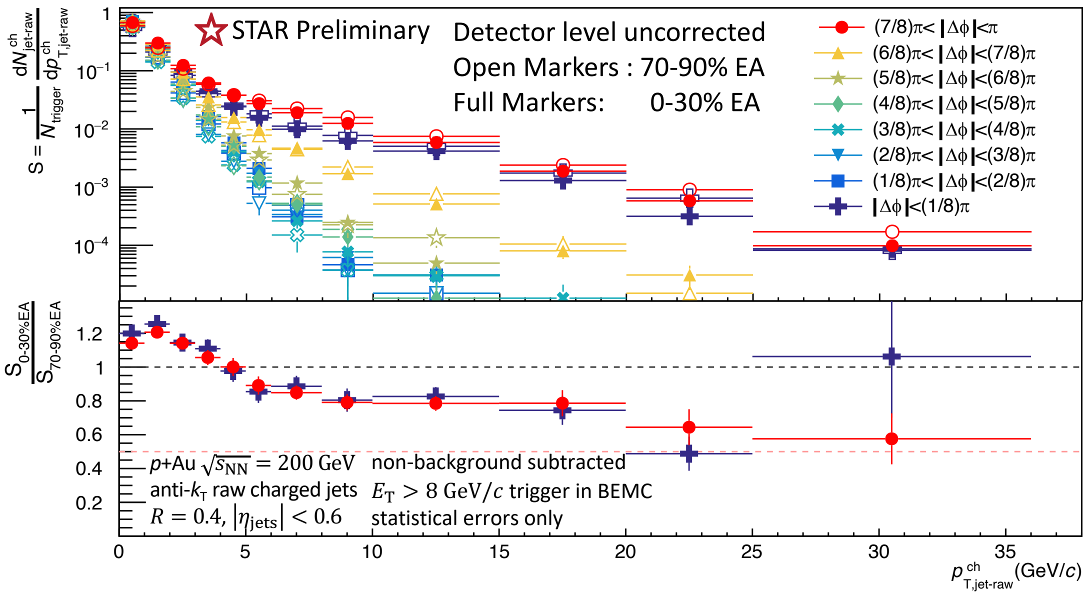

Figure 2. Top: raw, uncorrected, jet spectra per trigger in bins of high (0-30%) and low (70-90%) EA, sub-divided into bins of $|\phi_{\mathrm{jet}} - \phi_{\mathrm{trigger}}|$. Bottom: ratios of high-to-low EA jet spectra.

The primary feature of the data is a marked suppression in high to low EA in both the trigger-side and recoil-side spectra. It is of interest that both these suppression ratios are comparable. This is qualitatively different from jet suppression in A+A collisions, where the recoil jets traverse more QGP on average and are more suppressed than those on the trigger-side [15].

The lower values of the trigger-side relative to the recoil-side spectra in the top panel in Fig. 2 may be understood as a trigger selection bias. To leading order, the trigger-side and recoil-side jets represent recoiling jet pairs, which must balance in the sum of charged and neutral p_{T}. The trigger typically selects the jet with the leading $p^{\mathrm{neut}}_{\mathrm{T}}$, and thus biases the near-side spectra to be higher (lower) for neutral (charged) jets relative to the recoil-side. The data hint that, as expected, this bias decreases at higher $p^{\mathrm{ch}}_{\mathrm{T,jet}}$ energies.

A PYTHIA 8 [16] study is conducted to investigate if the spectra suppression might result from a trivial autocorrelation in which some jets that fall outside of the acceptance of the TPC (and therefore lower the spectra) also hit the BBC (and therefore simultaneously raise EA values). PYTHIA is used to generate inclusive 200 GeV pp events. The EA signal is taken as the sum of charged particles in $\eta_{\mathrm{EA-inner}}$ ($[-5, -3.4]$) and $\eta_{\mathrm{EA-outer}}$ ($[-3.4, -2]$). Neutral particles within η_{BEMC} are used as triggered, and charged jets are clustered

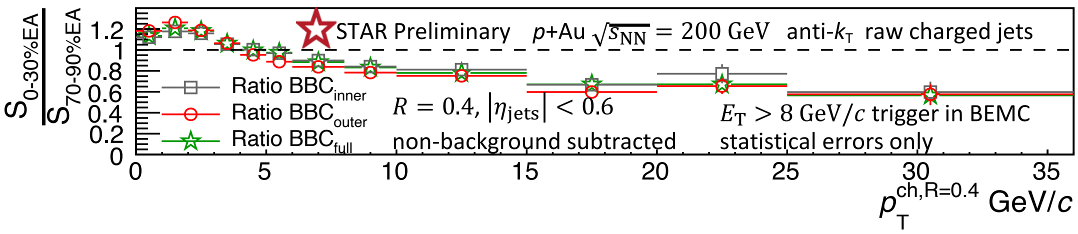

Figure 3. High to low EA ratio of recoil-side jet spectra ($|\phi_{\rm jet} - \phi_{\rm trigger}| > 7\pi/8$) per trigger when EA is determined by the inner, outer, and full BBC (the last of which is identical to values in bottom panel of Fig. 2).

in the TPC acceptance. The resulting semi-inclusive jet spectra unexpectedly show suppression in the ratio of high to low EA-binned data on an order of 20%, at 15 GeV/c to 60% at 30 GeV/c. This is true for EA acceptances at both $\eta_{\rm EA-inner}$ and $\eta_{\rm EA-outer}$. While the cause of suppression in the simulation is not yet fully understhood, the suppression from acceptance autocorrelation is quantified with a second run in which the EA acceptance in each event is set to the BBC farthest from the two highest p_T jets. For example, if the leading full jets had axes at $\eta = 0.4$ and -0.9, then EA acceptance (inner/outer) would be at the "opposite BBC" at [3.4, 5]/[2, 3.4]. The resulting jet spectra suppression decreases by about 10% when using $\eta_{\rm EA-outer}$, and is thereby attributed trival acceptance autocorrelations. However, the suppression increases slightly when using $\eta_{\rm EA-inner}$ for low $p_{\rm T}$ jets and is largely stable for jets above 14 GeV/c. Accordingly, the events from the STAR data were re-binned using $\eta_{\rm EA-inner}$ and $\eta_{\rm EA-outer}$. The resulting ratios of the recoil spectra are shown in Fig. 3. As observed, the effect is not statistically significant. Therefore, the spectra suppression does not result from a trivial autocorrelation from jet kinematics and acceptance of the TPC and EA.

4. Conclusions and remarks

Semi-inclusive jet spectra in both trigger and recoil azimuths are significantly suppressed in high EA relative to low EA. This result is not yet corrected for detector and jet reconstruction efficiency; however, the corrections are anticipated to largely cancel in ratio such that the suppression remains. PYTHIA simulations verify the suppression is not a trivial autocorrelation between jet kinematics and detector acceptance. PYTHIA also unexpectedly predicts significant suppression. Curiously, ALICE presented a similar result in this conference for a second jet quenching observable acoplanarity in pp collisions [17]. ALICE reported an unexpectedly broadening in acoplanarity in high multiplicity events relative to MB events accompanied by a similar currently unexplained broadening in the PYTHIA simulation. Measuring acoplanarity modification is principally a matter of separating spectra into fine bins in azimuth, and a natural expansion of this STAR analysis.

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